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NuMI LOW ENERGY TARGET SPECIFICATION

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Contents

1 Introduction and Scope of the Tender

This Specification, together with appropriate Engineering Drawings, covers the fabrication of the Low Energy (LE) target for the MINOS experiment to be held on the neutrino beam of the FNAL Main Injector.

The Tenderer is invited to make an offer for the manufacture, testing and delivery of the complete LE target at FNAL, Batavia, Illinois, in accordance to present Specification which will form the part of the contract. The target should be delivered completely assembled and ready for operation.

The price includes all mechanical, electrical, vacuum and hydraulic measurements and tests described in this Specification, together with a number of special tooling used in the target manufacture.

2 Purpose

2.1 Primary 120 GeV protons strike the LE target to produce short lived hadrons. The active part (the target core) of the LE target consists of 47 graphite segments soldered between two pipes with circulating water.

2.2 Due to the high radiation environment and interrelationship between components of the system, the replacement of the LE target is expensive and difficult. This Specification was created to minimize possible failures of the target and to provide at least one year of operation at the beam intensity 4×10^{13} protons per spill with repetition period 1.9 s.

3 General Requirements

3.1 The target should be manufactured according to requirements of the vacuum hygiene.

3.2 Insulation of the target core should provide the measurement of the charge induced when the proton beam knocks delta–rays out of the target.

3.3 The environment for storage and manufacturing must prevent corrosion and damage of separate target units.

3.4 The description of the manufacturing process should be provided for the LE target. This traveler should provide the consequence of manufacturing, inspection and tests, and recording of all required measurements and test results. Each LE target will be supplied with the traveler which includes:

1) The Serial Number and Date of Manufacture,
2) The Pertinent Process Information,
3) Required Mechanical Sizes,
4) Required Electrical Checks,
5) Required Vacuum Tests,
6) Required Hydraulic Tests.

Documents for the LE target should reference the serial number of the LE target on each page of the all documentation.

3.5 The inspection of conformance to the Engineering Drawings and Specifications should be performed after completing of the LE target. No targets should be manufactured until the approval of the test results had been given in written form.

4 Materials

4.1 No materials can be used if their life time, recommended by the Manufacturer, is exceeded. All materials should be stored according to the Manufacturer's requirements and recommendations.

4.2 Each part and sub-assembly should be degreased separately before assembling of the LE target to remove all grease, dirt and surface contaminations. The cleaner procedure must ensure that no damage will be happened during cleaning. The cleaner must not affect the anodized coat of the target supports. The Manufacturer should submit the description of the proposed cleaning agent and its mixture ratio to FNAL prior for its use.

4.3 Each detail must be inspected before assembling or sub-assembling. This inspection will verify the cross-section sizes of LE target units free from excessive warp. The inspection will also include the assurance that the LE target is free of burrs, and other injurious defects. Because the LE target is water cooled, the water flow must be tested and documented. The LE target traveler must include all pertinent data such as flow characteristics, mechanical sizes, any deviations from the prescribed tolerances, etc. The LE target traveler should be properly maintained the comprehensive document for manufacturing and testing of the target.

5 Low Energy Target Assembly

The LE target consists of:

- the target unit which represents the target core with water cooling system separated from the surrounding environment by the aluminum casing with the downstream beryllium window;
- the target canister bolted to the target unit and has the upstream beryllium window;
- the horizontal graphite segment for vertical monitoring of the proton beam position (Budal monitor);
- the protective tube using only for protection of the target casing from failure during storage, final assembly and shipment.

The main assembly of the LE target is given in the drawing 7589-00-00-00.

6 Target Unit

The assembly of the target unit is shown in the drawing 7589-01-00-00. It consists of :

- the target core and cooling piping;
- the target casing;
- the mounting flange;
- the vacuum pumping tubes, welded to the mounting flange;
- the feedthrough to lead out of Budal signals.

6.1 Target core

The target core is a row of 47 graphite segments. Segments of the target core will be cut from ZXF–5Q precision ground plates of Poco Graphite, Inc. with sizes $6.4\times100\times150$ mm^3 and tolerances for all dimensions $-0.025 \div +0.13$ mm by the electrical discharge machine and finally machined by the grinding machine. Surfaces of target segments should be carefully cleaned after machining with pure alcohol according to the drawing 7589-01-59-02.

Two 50 μm thick sheets made of the steel grade 15X28 (GOST 5632-82) are brazed in a vacuum to concave surfaces of the target segment using the amorphous solder with the melting temperature about $\sim$950°C. During the brazing process these sheets should be pressed to the segment by pipes with the same diameter as cooling ones.

Target segments with brazed sheets should be placed in the antistatic boxes using clean lint–free gloves. Each box should be numbered according to the sequence number of the target segment.

6.2 Cooling piping

Cooling piping consists of two long pipes (1230 mm length, 6 mm in diameter and 0.4 mm wall thickness), connecting ring, two bellows, two metal-ceramic adapters and two output (inlet and outlet) stainless steel pipes.

6.3 Support

The support is machined out of the high-strength aluminum alloy AMg6 (Russian grade, GOST 4784-74). Machining is performed by the CNC-Turner and coordinate boring machines according to appropriate Engineering Drawing. After machining surfaces of the support excepted the thread holes are coated with 15–20 μm alumina using the hard anodizing process.

Before anodizing the support should be carefully cleaned of grease and oil and etched in a 60°C (+10°C) solution of NaOH with the concentration of 50$\div$100 g/l during one min.

Supports are anodized in a water cooled bath filled with solution of sulfuric acid of grade "X" or "X4" (Russian standard, GOST 4204–77):

– the electrolyte concentration should be of 200 g/l ($\pm$10 g/l);

– the electrolyte temperature should be maintained at 10°C (+5°C);

– the current density should be of 2 A/dm^2 (+0.05 A/dm^2);

– the duration of anodizing should not be less than 50 min (+2 min).

After anodizing the support should be rinsed in flowing water at the temperature 10°C (+5°C) during one hour.

6.4 Assembly Procedure of Target Core and Cooling Piping

6.4.1 Soldering of Target Segment to the Long Pipes

Long pipes are rolled out of high plasticity steel grade 15X28 (USA analog grades: TP410, AMS5616), high-stable to corrosion and heat deformation. Two small rings of the stainless steel are brazed to the long pipes in a vacuum or in an argon environment with hard solder at the temperature about 1150°C. These small rings will be used for connection of the rest cooling system to the assembly of the soldered target core with long pipes.

Surfaces of brazed sheets of target segments, as well as the steel pipe are coated with the thin layer of a soft solder with melting temperature ~340°C.

Special tooling, provided necessary construction tolerances during and after soldering should be used for assembly of long pipes with set of target segments. The distance between target segments is provided by the corresponding spacer inserted between segments. This assembly is heated in argon environment to the temperature exceeding the melting point of a soft solder. The heating rate should be about 10°C/5 min.

After soldering the following measurements will be carried out:

1) location of target segments in a horizontal plane with respect to the longitudinal axis;

2) rotation of target segments around the vertical axis;

3) twist of the target core (a rotation of target segments around the longitudinal axis);

4) the length of graphite core;

5) the height clearance of the target core with welded cooling pipes.

6.4.2 Welding of the Rest Part of Cooling Piping

The rest part of cooling piping consists of two identical piping: inlet and outlet. Inlet (outlet) piping is an assembly made by welding of bellow, metal-ceramic adapter and several transition pipes. Welding of cooling piping should be made according to the Russian standards of welding and brazing for units used in the hot zones of nuclear reactors. Before welding all units should be cleaned by a pure acetone and alcohol. Each welded joint should be tested by the helium leak detector. The leakage should not be greater than 10^{-7} Torr·l/s.

Using of copper for joints of metal (high-stable to corrosion steel) and ceramic is excluded.

6.4.3 Final Assembly

An assembly should be carried out in an air conditioned clean room by white dressed personal using white lint–free gloves. Toolings and instruments for an assembly should be clean, free of grease, dust and oil.

For the final assembly of the target core with cooling piping the special tooling for soldering of long cooling pipes with target segments and tooling given in the drawing 7589-01-04-01 will be used. Joints of the connecting ring with long pipes at the downstream end, as well as inlet and outlet piping with long pipes will be made by laser welding.

Five supports, constructed according to the drawing 7589-01-50-04, should be uniformly placed along the target core. After the final assembly of the core with cooling piping the following tests will be carried out:

1) the vacuum test at operating vacuum 10^{-3} Torr with the help of the helium leak detector; the leakage should not exceed 10^{-7} Torr·l/s;

2) hydraulic tests:

   a) the static test at pressure 0.3 MPa during 30 min, the leakage is not allowed;

   b) the test of water flow rate at pressure drop of 0.1 MPa; the water flow rate should not be less than 3.5 l/min.

After hydraulic tests the piping will be dried by the flow of the warm dry air.

6.5 Target Casing

The target casing is a vacuum-tight envelope of the target core and at the same time serves as its support by means of five uniformly spaced supports. It consists of:

- the pipe;
- the bimetallic adapter;
- the metal-ceramic adapter;
- the stainless steel pipe;
- the downstream beryllium window;
- the ceramic ring.

6.5.1 Pipe

The pipe is made of German Grade aluminum alloy, named ALUMAN-100. All sizes of this pipe is shown in the drawing 7589-01-01-01.

6.5.2 Bimetallic Adapter

The bimetallic adapter consists of the stainless steel pipe and the aluminum bushing (drawing 7589-01-10-00). Initially the 30 μm thick aluminum layer is sprayed in vacuum in the lateral side of stainless steel pipe. The diameter ϕ32 mm should be machined out according to the size of the detail (drawing 7589-01-01-01) with the gap less than 0.02 mm. The pipe from the side of aluminum layer is inserted into the hole of bushing. After that, the electron beam welding is performed as it is shown in an appropriate Engineering Drawing. The quality of welding will be tested by the helium leak detector. The leakage should not be greater than 10^{-7} Torr·l/s.

6.5.3 Metal-Ceramic Adapter

The metal-ceramic adapter is the product developed and constructed in the Moscow Institute of Vacuum Technology. It consists of high alumina (Russian grade ceramic BK-94) tube with two kovar tubes brazed by a copper solder to the ceramic one. It should be tested by the helium leak detector as mentioned above.

6.5.4 Downstream Beryllium Window

The downstream beryllium window will be constructed using the diffusion welding of the 0.5 mm thick beryllium sheet to the details, made of an aluminum alloy AMg6, as it is shown in the drawing 7589-01-30-00. The beryllium grade PF-16 of Brush Wellman, Inc. should be used as the window material.

The assembly, shown in the drawing 7589-01-00-00, will be heated in a vacuum to the temperature of about 500°C. After heating the welded units should be pressed together in special tooling provided welding pressure of 40–50 MPa.

6.5.5 Ceramic Ring

The ceramic ring is not a part of the casing but will be used for insulation of the target casing from the mounting flange and should be installed during the assembly of the target casing. It should be made of the high-alumina ceramic, for example, technical sapphire.

6.5.6 Assembly Procedure

The sequence of the casing assembly is the following:

– the long aluminum pipe is welded to the bimetallic adapter by the electron beam in a vacuum;

– the ceramic ring is inserted onto the stainless steel pipe of the bimetallic adapter;

– two rings are welded to metal-ceramic adapter;

– the bimetallic adapter is welded by the electron beam in a vacuum to the metal-ceramic adapter;

– the downstream beryllium window is welded to the aluminum pipe by the electron beam;

Vacuum tightness tests of each welded joint should be made during the assembly, as it was described above.

After the assembly of the target casing the final vacuum tests will be carried out by the helium leak detector. The leakage should not be greater than 10^{-7} Torr·l/s. To provide the transverse stability of the aluminum pipe the uniformly spaced target core supports should be used.

6.6 Mounting Flange

The mounting flange is destined for:

- welding of the target casing to mounting flange;
- welding of outlet and inlet pipes of the cooling system;
- welding of pipes for vacuum pumping.

After procedure described in three last item the mounting flange should be bolted to the target canister.

The mounting flange is machined out of well weldable, stable to corrosion stainless steel 13X18N10T (Russian grade, GOST 5632-81). Preliminary machining, as well as conflat junction, the hole and the drain for casing welding are performed by the CNC-turner. The rest part will be machined out by the coordinate boring machine according to the appropriate Engineering Drawing.

6.7 Protective Tube

The protective tube is destined to protect the target casing during the final target assembly, storage and shipment. It is constructed from a tube 45 mm in diameter and 3 mm wall thickness made of well weldable aluminum alloy AMg1 (Russian grade, GOST 18475-82). Machining of this tube should be done according to the drawing 7589-03-00-02. The cover and the flange fabricated according to appropriate Engineering Drawings should be welded to the tube as it is shown in the drawing 7589-03-00-00.

6.8 Assembly of the Target Unit

The sequence of assembly of the target unit is the following:

– the target casing is welded to the mounting flange; tooling for welding should provide the deviation of the casing downstream end from the axis of mounting flange not greater than 3 mrad;

– pipes for vacuum pumping, the feedthrough for the electrical signal are welded to the mounting flange;

– the target unit is inserted into the target casing in such a way that inlet and outlet pipes would pass through the corresponding holes in the mounting flange; after that the inlet and outlet pipes are welded to the mounting flange.

The hydraulic tests should be carried out after the assembly of the target unit (see 6.4.3). The protective tube should be bolted to the mounting flange after completing of the tests.

7 Target Canister

The target canister together with the target casing provides the vacuum envelope of the LE target.

The construction of the target canister will be made of a solid peace of aluminum alloy AMg6 in three steps:

– preliminary machining with the rough tolerances about 2 mm by the CNC-turner and coordinate boring machines according to appropriate Engineering Drawings;

– before the final machining the target canister should be annealed as follows:

  ↪ heating in the electrical heater to the uniform temperature 280°C (+20°C);

  ↪ during the annealing cycle the temperature should be maintained at 280°C (+20°C) for minimum of 2 hours (+5 min);

  ↪ the target canister is cooled by the air natural convection;

– the final machining of the target canister will be made by the CNC-turner and coordinate boring machines according to the drawing 7589-02-00-00. The geometrical measurements should be made after the final machining to check the construction tolerances.

Vacuum tests will be made using the technological complete set as it is shown in the drawing 7589-02-01-00. Test will be made by the helium leak detector. The leakage should not be greater than 10^{-7} Torr·l/s.

8 Vertical Budal Monitor

The vertical Budal monitor is a graphite plate placed in the horizontal plane and insulated from the rest part of the monitor design. It should provide an accurate measurements of the vertical beam position on the target by beam scanning in the vertical direction and measuring the charge induced in a graphite plate due to δ-electrons. The graphite plate is pressed between the bracket and the pressing plate. A necessary pressure (0.3 MPa) is provided by the coil spring. The graphite plate is cooled by two ways: radiation and by convection of the heated target canister. Heating of the target canister is produced due to the heat conductivity on the path: bracket, flange and aluminum gasket.

8.1 Graphite Plate

The graphite plate is cut from the ZXF-5Q grade with inventory thickness of 6.4 mm by the electrical discharge machine. Rounding of plate corners (drawing 7589-04-00-01) will be made by the grinding machine. The special hole with 9 μm nickel coating will be used for the connection of a signal wire.

8.2 Flange

The flange is made of aluminum alloy AMg6. Machining of the flange will be performed by the CNC-turner according to the appropriate Engineering Drawings. The holes for carving will be made by the coordinate boring machine.

8.3 Bracket

The bracket is machined out of aluminum alloy AMg6 by the CNC-turner and the continuous milling machine according to the appropriate Engineering Drawing. The bracket should have a hard anodized coating 15–20 μm thickness. The process of hard anodizing is described in section 6.3.

8.4 Pressing Plate

The pressing plate is machined out by the continuous milling machine and hard anodized (see 6.3) according to appropriate Engineering Drawing.

8.5 Stud

The stud is constructed according to appropriate Engineering Drawing and hard anodized, as described in section 6.3.

8.6 Assembly

The assembly should be carried out in an air conditioned clean room by the white dressed personal using white lint–free gloves. Toolings and instruments for an assembly should be clean, free of grease, dust and oil. The sequence of the assembly of the vertical Budal monitor is the following:

- the bracket is bolted to the flange;
- the graphite plate is placed on the bracket;
- the pressing plate is placed on the graphite plate;
- the stud together with spring is inserted into the holes in pressing plate, graphite plate and bracket;
- finally, the spring should be completelly compressed by the nut;
- the 0.5 mm nickel wire should be used for the connection of the graphite plate with the fourth pin of the feedthrough. This wire should be looped at the one end. This loop is pressed to the nickel layer of the graphite plate with help of the M2 screw. The pin, which is another end of this wire, is similar to that used in the socket connector type GRPPMU-64GPP2-V and has the elliptic hole with the smaller half-axis equal to 0.39mm. The pre-stress of the connection of this pin with the 0.81 mm pin of the feedthrough will be enough to provide the reliable contact between them.

The test of the resistance of the graphite plate to the ground should be carried out after the assembly. It should not be less than 10 MOhm at voltage of 100 V.

9 General Assembly of the Low Energy Target

An assembly should be carried out in an air conditioned clean room by white dressed personal using white lint–free gloves. Toolings and instruments for an assembly should be clean, free of grease, dust and oil. Gaskets, as well as teeth of conflat flanges should be cleaned by a pure acetone and alcohol and be free of scratches, slivers and burrs.

The sequence of the target assembly is the following:

– the vertical Budal monitor is bolted to the target canister;

– the proper connector lugs should be attached to one end of each of two 0.5 mm nickel wires for the connection with cooling pipes. These lugs are pressed between cooling pipes and clamp (item 10, drawing 7589-01-00-00). Elliptic pins which are other ends of this wires are similar to those described in section 8.7. These pins are connected to the second and third pins of the feedthrough;

– the path of the wire, connecting the graphite plate of the vertical Budal monitor with the pin of the feedthrough, should exclude any intermediate contact between the wire and other units of the target design.

Following tests will be carried out after the final assembly of the LE target:

1) the final vacuum test at operating vacuum 10^{-3} Torr will be performed by the helium leak detector; the leakage should not be greater than 10^{-7} Torr·l/s; the protective tube should be dismounted before and bolted to mounting flange after vacuum testing; the target volume should be filled by a pure nitrogen or argon after vacuum testing;

2) final hydraulic tests (see 6.4.3);

3) final electrical tests, which are measurements of the resistance at voltage of 100 V between:

   a) the target core and the ground (mounting flange);
   b) the target core and the casing;
   c) the segment of vertical monitoring and the ground.

10 Low Energy Target Attachment and Alignment

The LE target attachment to the target support tube is given in the drawing 7756-00-00-00. The LE target is attached to the target support tube using intermediate tube with upstream and downstream flanges. The downstream flange of the target canister has spherical surface and is supported by the conical ring, bolted to the target support tube in its internal surface.

10.1 Intermediate Tube

The intermediate tube should be constructed according to appropriate Engineering Drawing with the sequence, described in section 7.

10.2 Flange of the Target Support Tube

The flange of the target support tube is made of stable to corrosion steel alloy 30X13 according to appropriate Engineering Drawing by the CNC-turner; all holes will be made by the coordinate boring machine. To decrease the friction between alignment bolts and contacting surfaces of a flange, the hardness of the flange, as well as alignment bolts, will be increased up to 40 units of Rockwell Hardness.

10.3 System of Alignment

The system of alignment of the LE target includes the pair "conic–sphere", formed by the conical ring, bolted to the target support tube and spherical surfaces of the downstream flange of the target canister, and four alignment bolts screwed in the upstream flange of the intermediate tube. It should provide the accurate positioning of the target with respect to the outer support carrier tube.

10.4 Attachment Procedure

Attachment of the target to the target support tube is the following:

– the intermediate tube is bolted with target canister;

– the target support tube is placed in a vertical direction;

– the assembly of the target and the intermediate tube is carefully inserted into the target support tube until the spherical part of the canister flange is touching with conical ring;

– the upstream flange of the target support tube is bolted to the target support tube;

– four alignment and four preload bolts, using spring washers for assuring bolt preload during thermal cycles, are screwed into corresponding thread holes;

– this assembly is located in horizontal direction on two prisms;

– the protective tube is dismounted;

– the alignment of the target with respect to the outer support carrier tube is carried out;

– the target casing is supported by a spider-support after the completing of alignment, described in the next section.

11 Target Casing Spider Support

The spider support provides additional support of the target casing. It consists of three supports perpendicular to the target support tube and located at 120° from one to another. The vertical support has not a spring and its length is defined by a weak touching to the target casing. Two other supports have spring touching with the casing in order to prevent any forces to the thin target casing. Each support has the metal-ceramic adapter for the insulation of the target casing from the target support tube.

12 Shipment

12.1 The Manufacturer is responsible for the proper packing or crating to ensure that damage will not be occured during shipment.

12.2 The water passage, if present, should be purged with clean compressed air to ensure that the water passage is clear of any and all contaminates and moisture prior to shipment. The water passage of the target should be properly capped to prevent it contamination, which would subsequently degrade the flow capacity of the target cooling system.

12.3 The outside of the shipping container should be marked in two places with the Seller's name, LE target serial numbers.

13 Acceptance Inspection

The Buyer reserves the right to repeat any tests referred in this Specification upon receipt it at FNAL and to make new tests to be sure of the target quality prior to acceptance.